

# Ambient Conditions and Altitude Effects on PEMFC Hybrid Vehicle Performance

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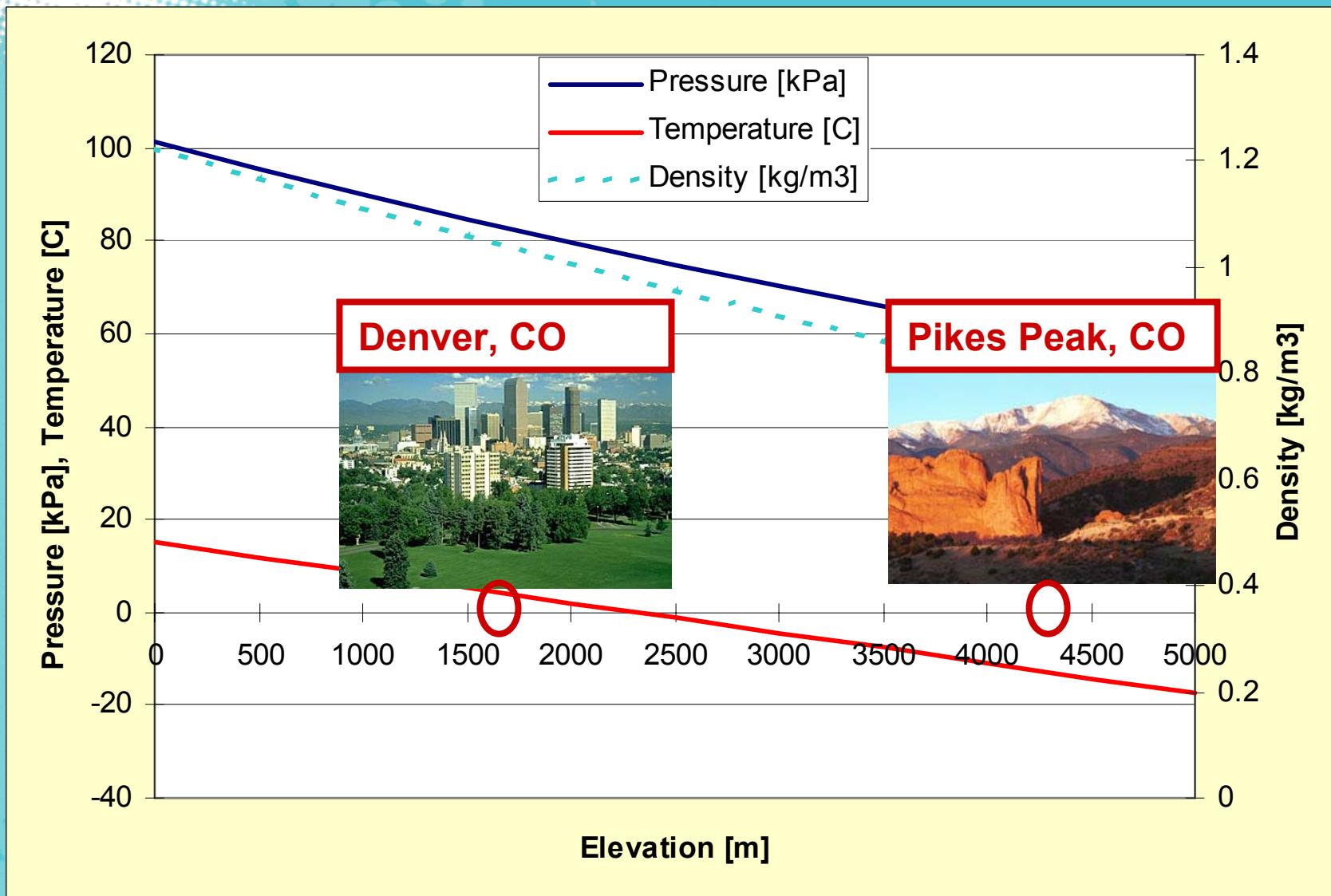
National Renewable Energy Laboratory (NREL)  
Golden, CO



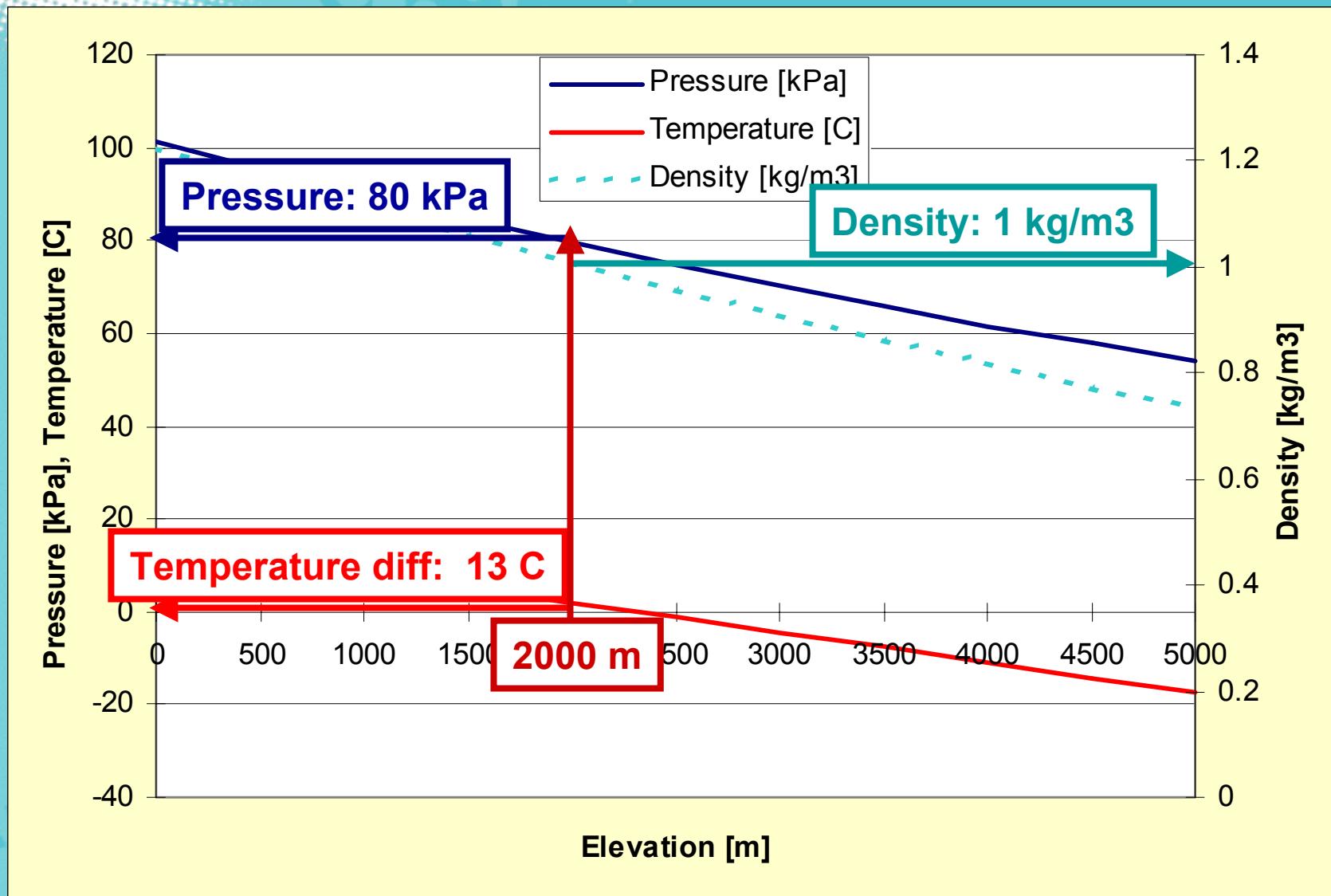
# Introduction

- Ambient conditions impact on vehicle performance
  - Air temperature
  - Air relative humidity
  - Altitude
    - Air pressure
    - Air density
- Higher altitude:
  - Lower air pressure, temperature and density**
    - + Lower aerodynamic resistance
    - Lower performance of system components

# Ambient Conditions



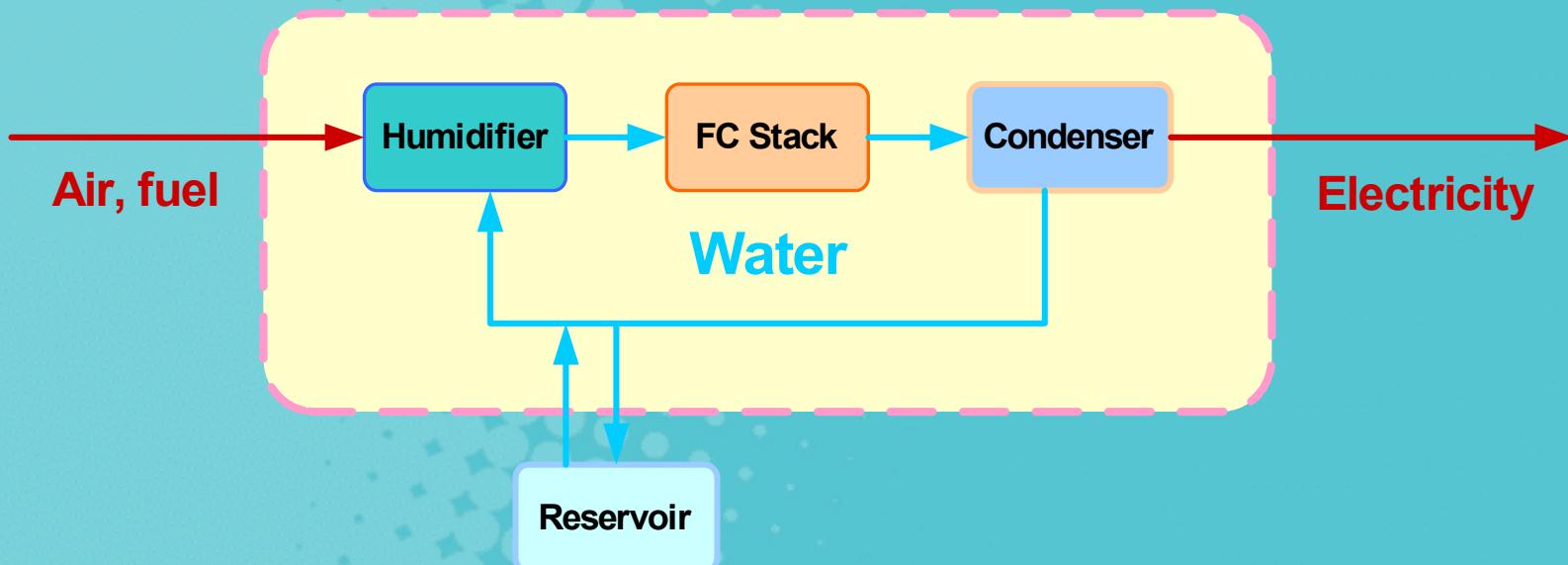
# Ambient Conditions



# Introduction

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- Higher altitude:
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    - + Lower aerodynamic resistance
    - Lower performance of system components
- Performance also dependent on drive cycle & control strategy
- **FOCUS:** Fuel cell system water balance and vehicle fuel consumption

# Water Balance



- Neutral water balance:

Water  
needed for  
humidification

Water  
condensed out  
of the exhaust

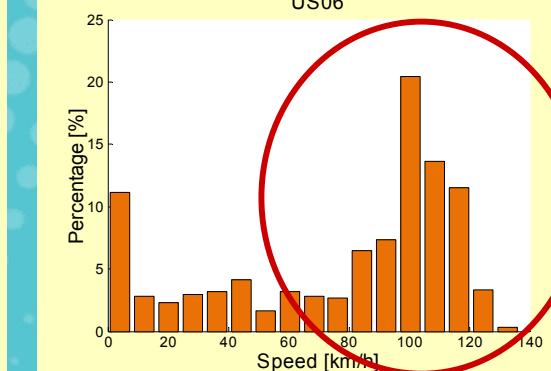
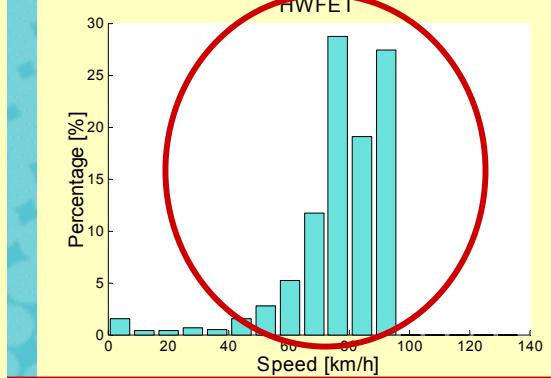
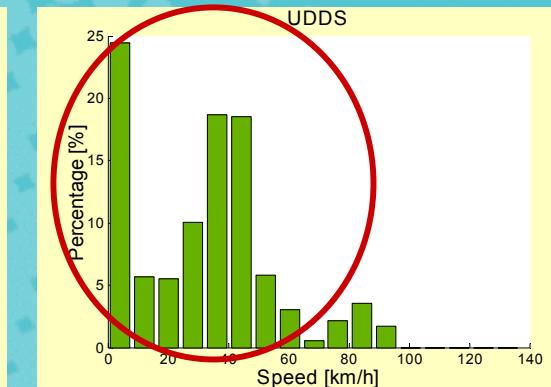
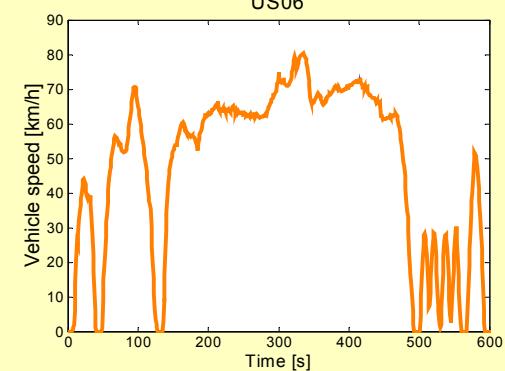
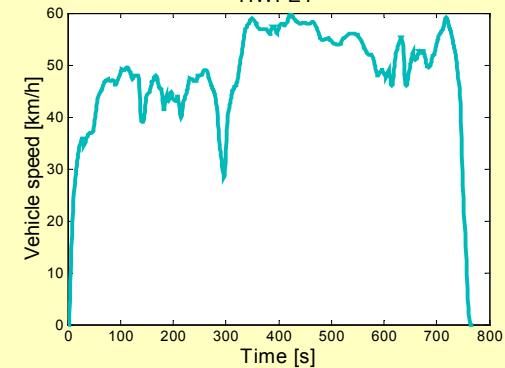
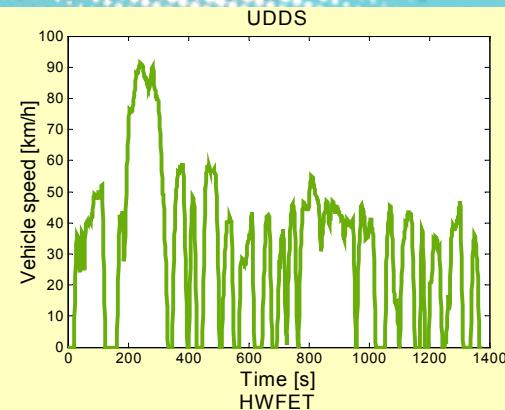
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## Baseline

- **Compact hybrid electric vehicle**
  - 50 kW pressurized PEM fuel cell system
  - 70 kW AC induction motor/inverter
  - 6 Ah Li-ion battery pack



# Speed Profiles



**UDDS: Urban drive cycle**

**Max acc.: 1.48 m/s<sup>2</sup>**

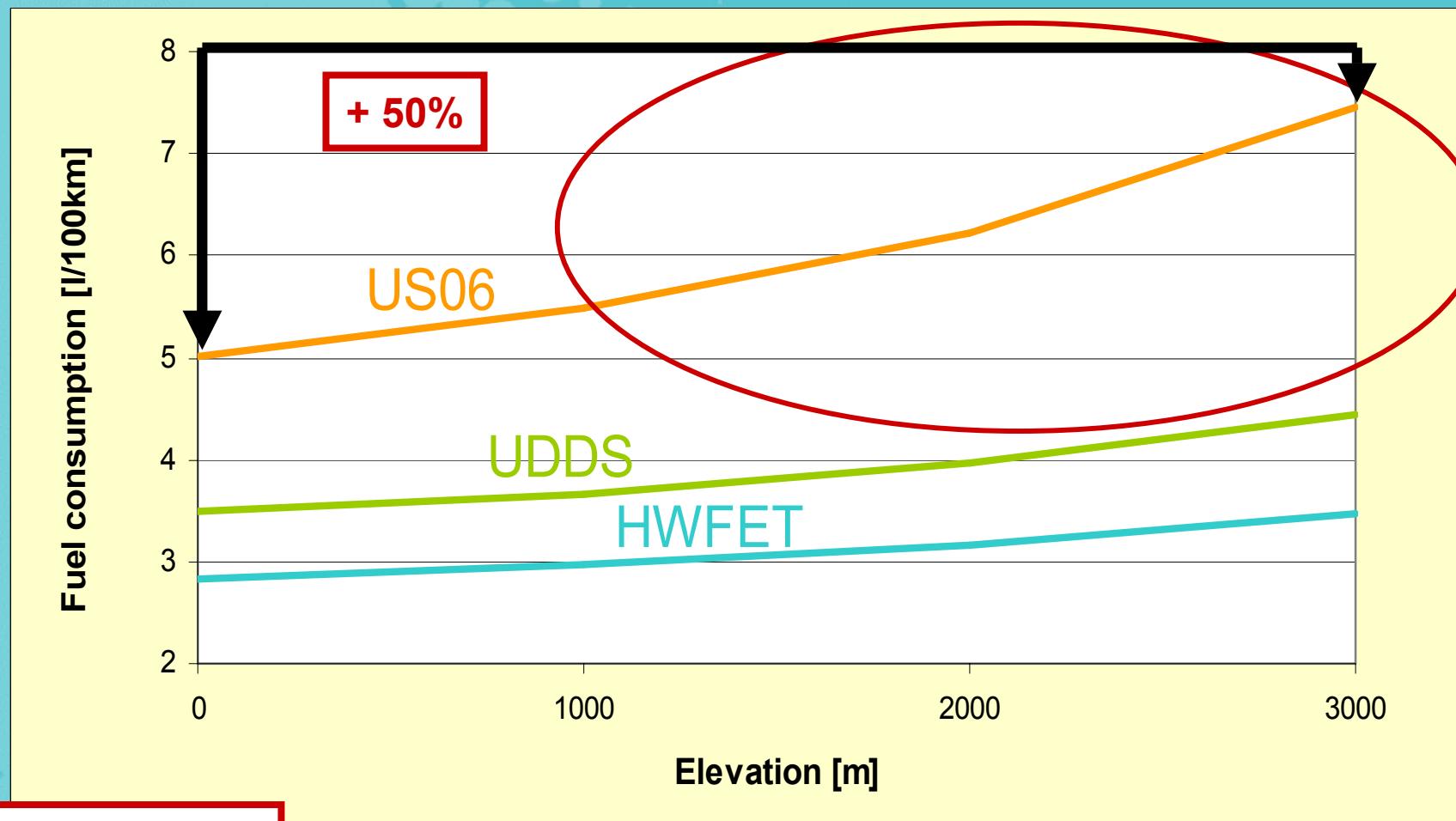
**HWFET: High speed, medium-acc. highway drive cycle**

**Max acc.: 1.43 m/s<sup>2</sup>**

**US06: High-speed & high-acc. highway drive cycle**

**Max acc.: 3.76 m/s<sup>2</sup>**

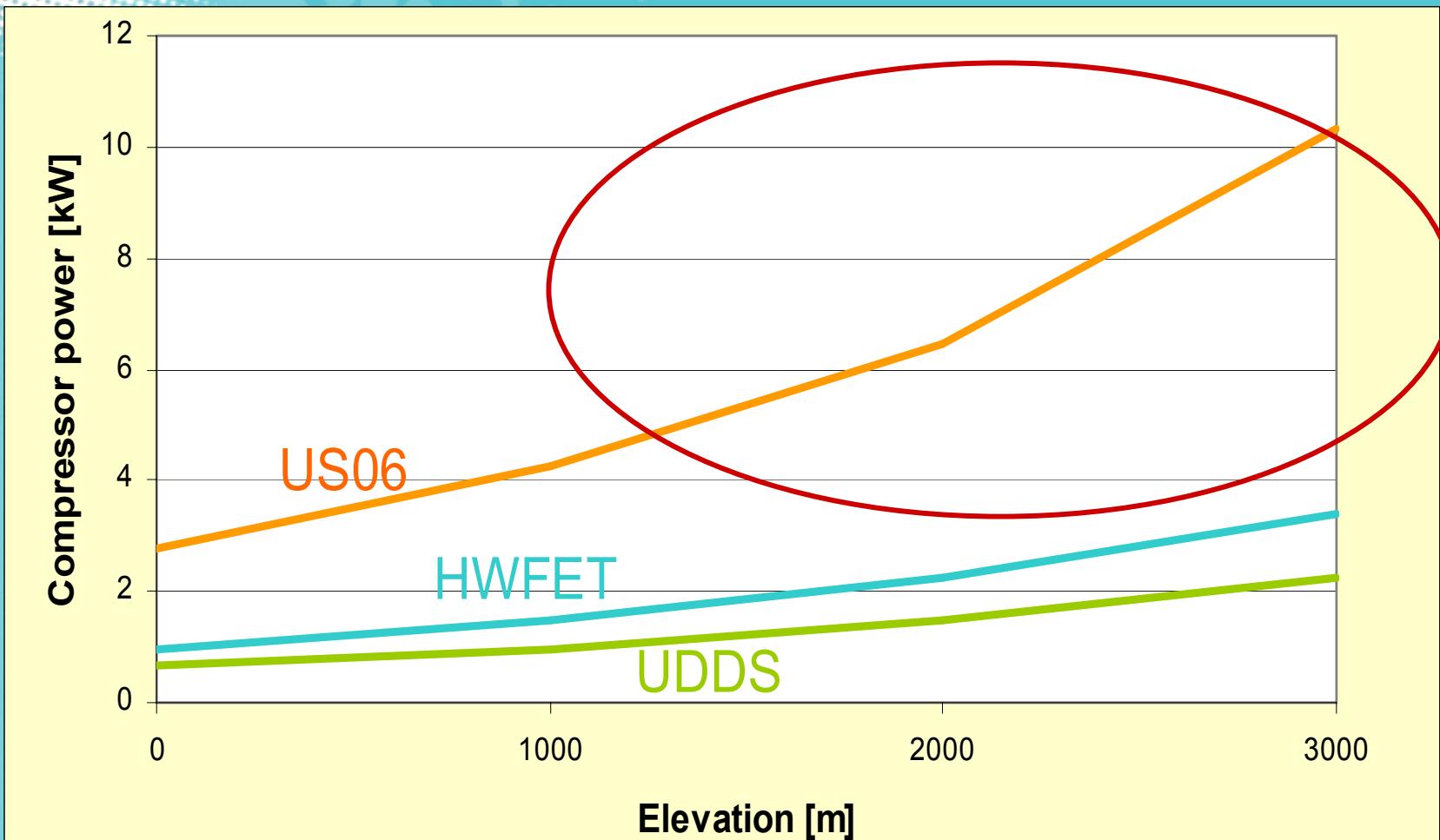
# Fuel Consumption as Function of Altitude & Drive Cycle



T=20C, RH=50%  
Hot start

Fuel consumption increases with 50% in high-power US06 cycle

## Compressor Power as Function of Altitude & Drive Cycle

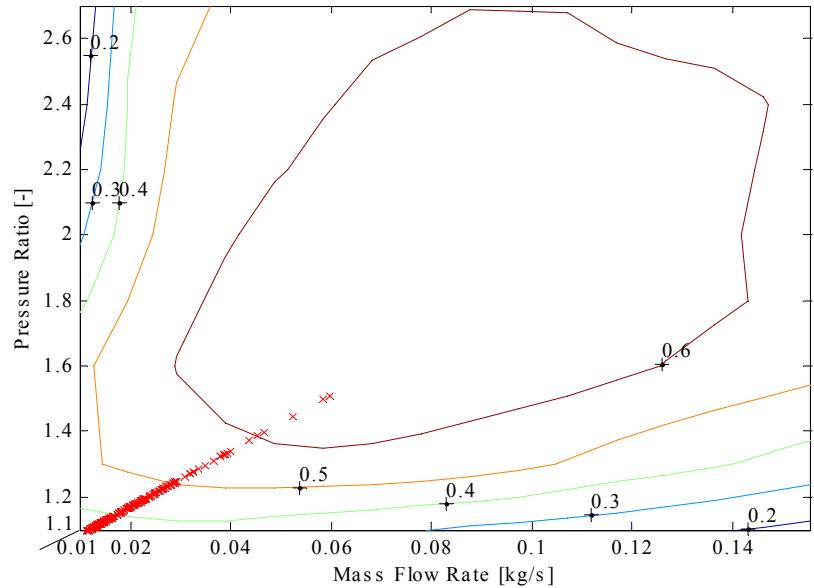


Compressor works harder to achieve desired pressure ratio (due to assumption). This effect is amplified in high-power cycles at high altitude.

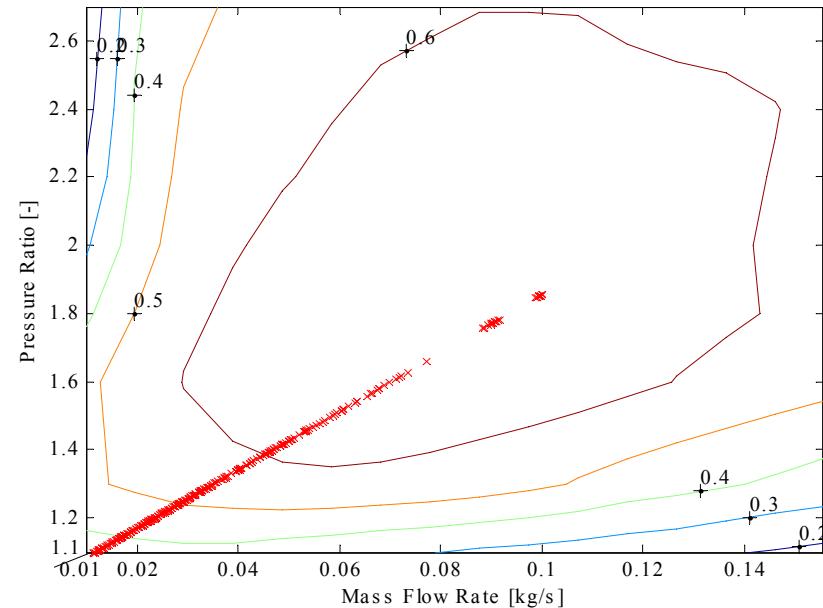
T=20C, RH=50%  
Hot start

## Compressor Power as Function of Altitude &amp; Drive Cycle

UDDS



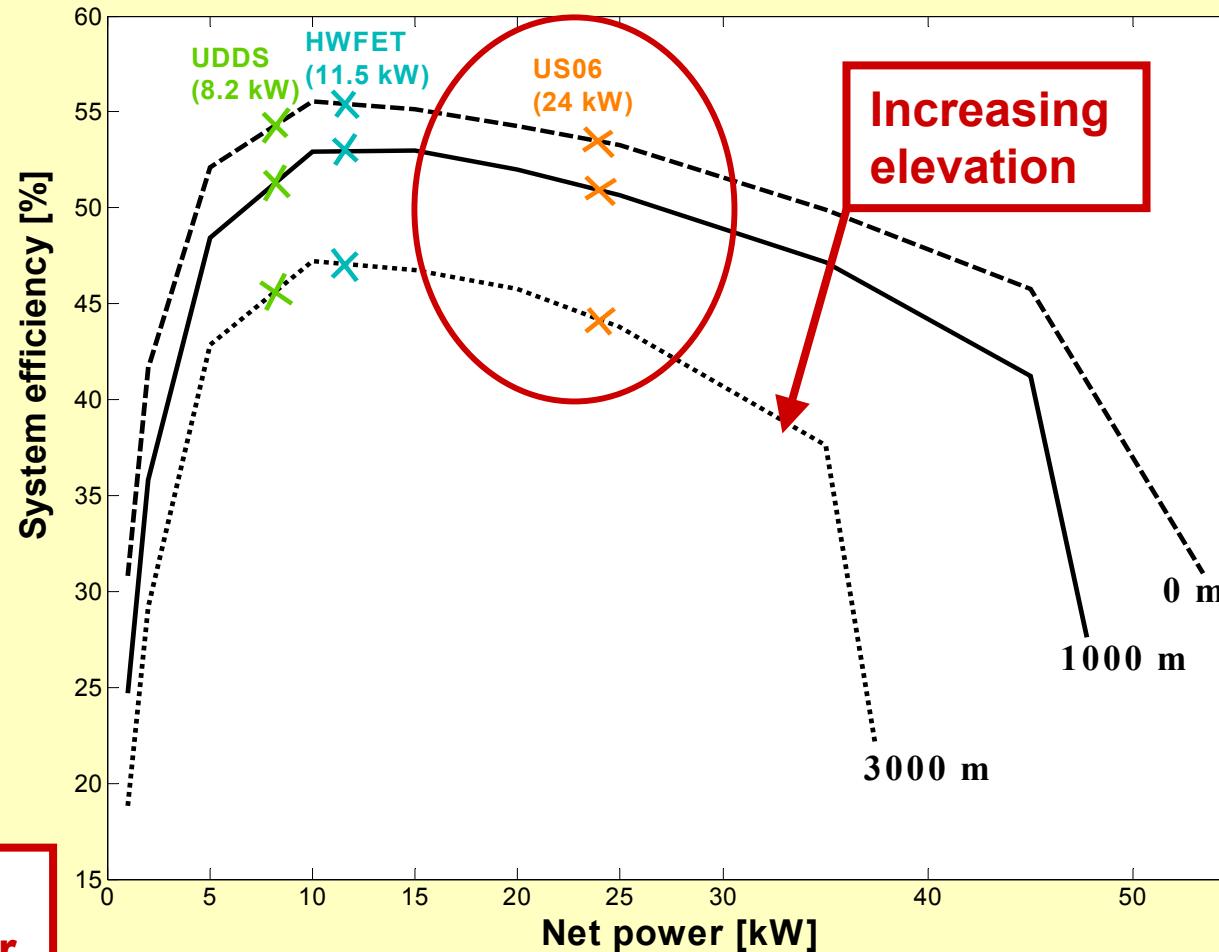
US06



T=20C, RH=50%  
Hot start

Assumption: operating pressure is linear to power demand.

# Altitude Effects System Efficiency & Net Power

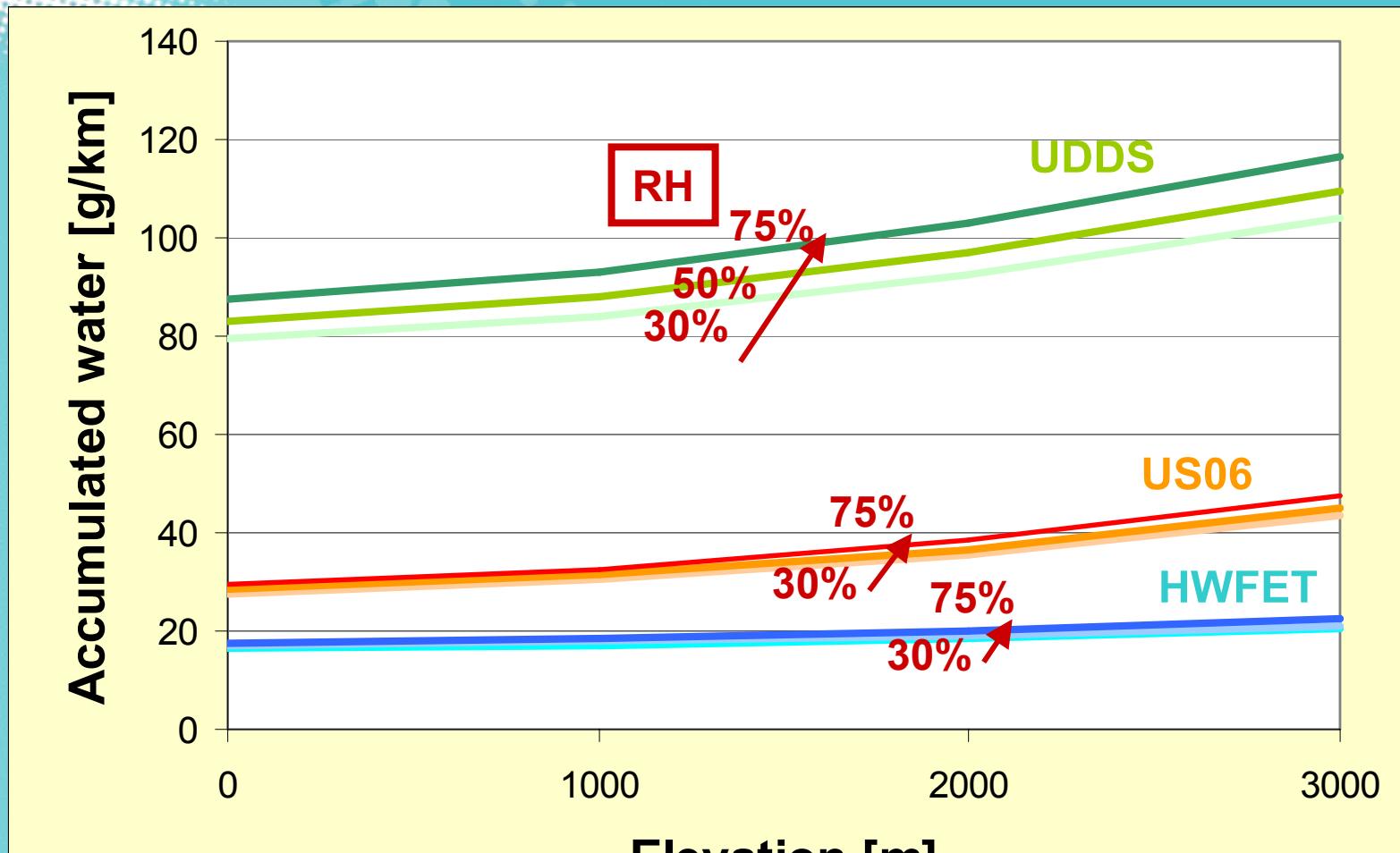


X:

Average electr.  
power load of  
the vehicle

- System efficiency is highest in HWFET cycle.
- System efficiency is about equal in UDDS and US06 cycle.

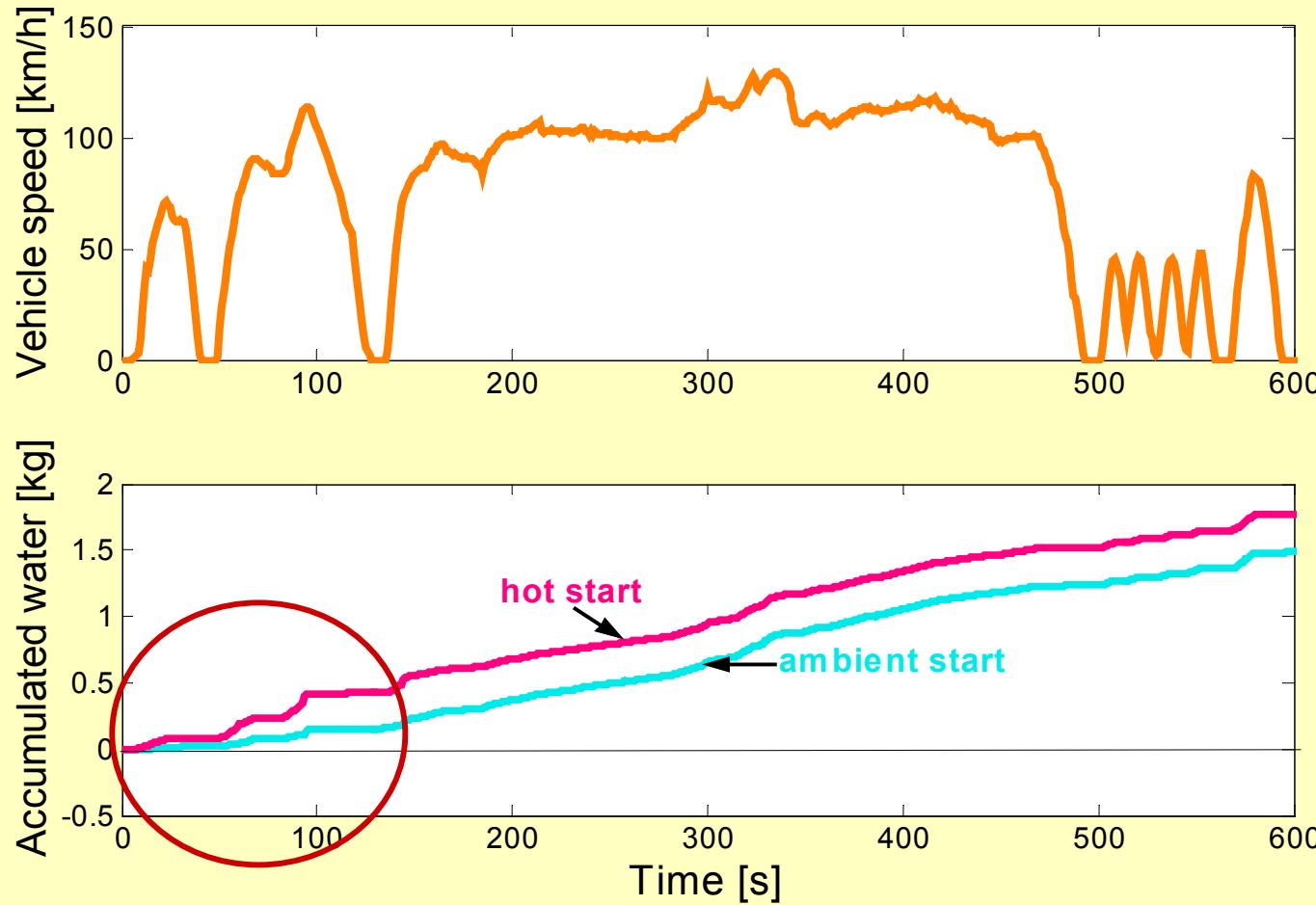
## Effect of Ambient Rel.Humidity & Altitude on Water Balance



- Ambient RH affects water balance more in urban UDDS than in US06 or HWFET.
- Water balance increases with increasing altitude.

# Startup Conditions Affects Water Balance

US06

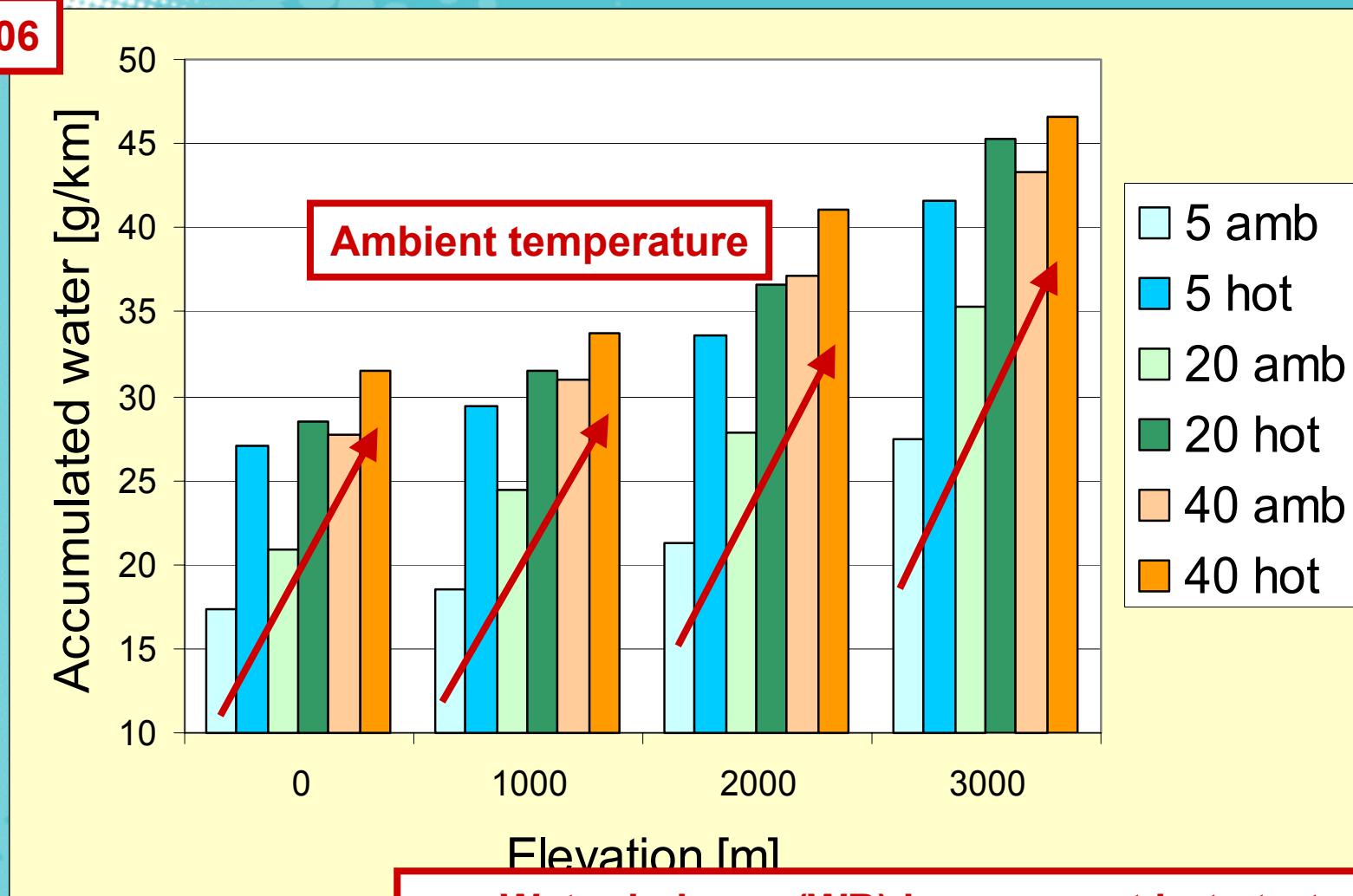


T=20C, RH=50%  
Sea-level

Ambient start: water balance positive as condenser begins to become effective

## Water Balance Affected by Start & Ambient Temp. & Altitude

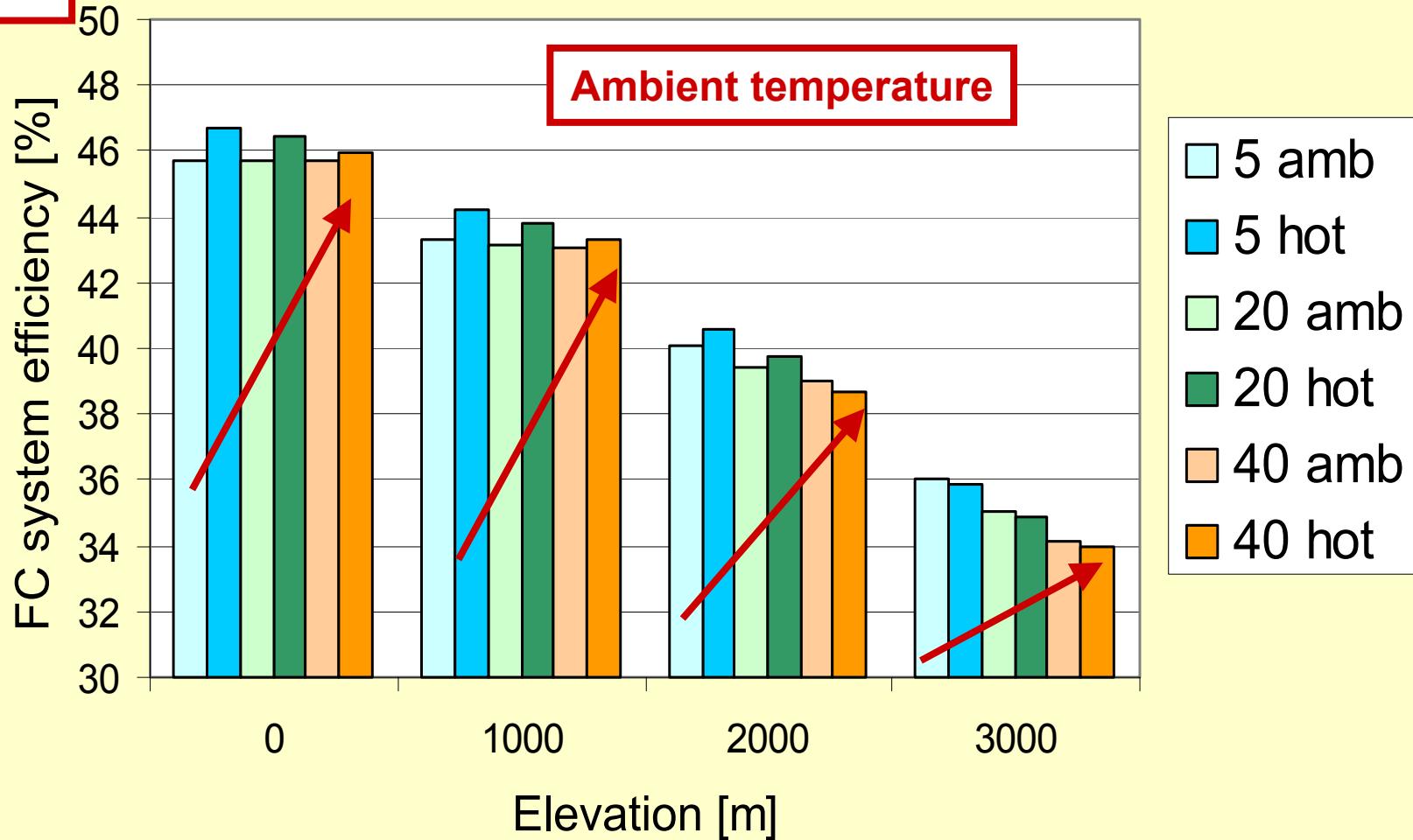
US06



- Water balance (WB) increases at hot start.
- WB increases at increasing ambient temperature.
- WB increases at higher elevation.

## System Efficiency Affected by Ambient Temp. & Altitude

**US06**



Ambient temperature

- 5 amb
- 5 hot
- 20 amb
- 20 hot
- 40 amb
- 40 hot

## Conclusions

- FC system and vehicle performance affected by ambient conditions, altitude and drive cycles.
- 50% increase in fuel consumption in high-speed drive cycles, eg. US06, going from sea level to 3000 m.
- FC system efficiency decreases with increasing elevation

## Conclusions (cont'd)

- Water balance is not an issue for longer than 100 sec. at ambient startup conditions.
- Ambient relative humidity affects water balance more in urban UDDS than highway cycles.